Seismic Analysis of RC Frame with Brick Infill

NIT Rourkela

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
Bachelor of Technology

In

Civil Engineering

By

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Under the guidance of

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Department of Civil Engineering
National Institute of Technology
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National Institute of Technology Rourkela

Certificate

This is to certify that the project entitled "**Seismic Analysis of RC Frame with Brick Infill**" submitted by **Mr.Ishan Jaimin** [Roll No. 110CE0354] in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Civil engineering at the National Institute of Technology Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge the matter embodied in the project has not been submitted to any other university/institute for the award of any degree or diploma.

Date: 14 May 2014.

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Ishan Jaimin

110CE0354

B.Tech 8th Semester

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LIST OF ABBREVIATIONS

ASCE	=	American Society of Civil Engineers
DL	=	Dead load
EQx	=	Earthquake load in X-direction
FEA	=	Finite element analysis
FEMA	=	Federal Emergency Management Agency
IS	=	Indian Standards
LL	=	Live load
RC	=	Reinforced Concrete

ABSTRACT

Reinforced concrete frames with masonry infill walls are a common practice in countries like India, where the region is prone to seismic activity. Generally the masonry infill walls are treated as nonstructural element in structural analysis and only the contribution of its mass is considered and it's structural properties like strength and stiffness is generally not considered. The structures in high seismic areas are greatly vulnerable to severe damages. Apart from the gravity load structure has to withstand to lateral load which may develop high stresses. Now day's reinforced concrete frames are most common in building construction practice around the globe. The vertical gap in reinforced concrete frames i.e. created by the columns and beams are generally filled in by brick or masonry and it is referred as brick infill wall or panels. When the construction of frame is done, these walls are built of brunt clay bricks in cement mortar. These walls are typically of 200 to 115 mm thick. Due to functional requirements the openings is provided in the frames for windows and doors etc.

INTRODUCTION

Earthquake is responsible for ground motion in random fashion, both horizontally and vertically, in all directions radiating from the epicenter. Consequently, structures founded in ground vibrate, inducing inertial forces on them. The structures in high seismic areas are greatly vulnerable to severe damages. Apart from the gravity load structure has to withstand to lateral load which may develop high stresses. Nowadays reinforced concrete frames are most common in building construction practice around the globe. The vertical gap in reinforced concrete frames i.e. created by the columns and beams are generally filled in by brick or masonry and it is referred as brick infill wall or panels. When the construction of frame is done, these walls are built of brunt clay bricks in cement mortar. These walls are typically of 200 to 115 mm thick .Due to functional requirements the openings is provided in the frames for windows and doors etc.

Figure 1 Full and Partial Infill Structure

(www.masonryedge.com)

The major reason behind the use of infill in building is the ease with which it can be constructed that is it generally requires the locally available material. Again it has the good sound proofing and heat insulating properties those results in the greater comfort for the inhabitants of the buildings.

Reinforced concrete frames with masonry infill walls are a common practice in countries like India, where the region is prone to seismic activity. Generally the masonry infill walls are treated as nonstructural element in structural analysis and only the contribution of its mass is considered and it’s structural properties like strength and stiffness is generally not considered. Although it contributes significantly to the lateral stiffness of the frame structures. There are no such specific references to infill walls in the Indian seismic standard (IS 1893:2002) that is currently used in India. One of the drawbacks of neglecting the infill as a structural member is the irregularities in the building caused by the uncertain position of infill and openings in them.

The traditional modeling of Reinforced concrete frame structures in which the effect of infill is not considered assumes the structures more flexible than they really are. Because of this reason the building codes obtrudes an upper limit to the natural period of a structure. The contradiction may occur in the analysis and proportioning of structural member in traditional modeling because it does not take strength and stiffness characteristic into account. Actually there is increase in the overall stiffness of the structure by the effect of infill walls which finally leads to the shorter time periods.

To understand the effect of infill masonry on the lateral strength and stiffness of structures various experiments have been conducted since early 50's. Actually the lateral load carrying mechanism is modified from the primary frame action to primary truss action by the effect of infill, which causes the increase in axial force and decrease in bending moment and shear force of the frame members. There is generally increase in damping of structures due to the generation of cracks with growing lateral drift. The infill walls may adversely affect the structure during the seismic excitation if it is not placed properly. The non-appearance of infill wall in a certain storey may lead to the soft storey effect which is one of the major ill effects of the infill walls.

OBJECTIVES

The objectives of present work are:

1. To study the seismic behavior of reinforced concrete frame infilled by brick masonry.

2. To study the seismic behavior of reinforced concrete frame infilled by brick masonry with different opening sizes.

SCOPE

The current study is involved only with the macro models of infill walls because the models are appropriate for practicing engineers due to its simplicity.

- This study concerns only with the reinforced concrete moment resisting frame with brick infill walls and the brick infill wall with openings.

- This study involves a theoretical 6 storey building with normal floor loading and infill thickness 230 mm in cement sand mortar ratio 1:3. The openings considered are typical centrally located square type with two different sizes of 20% and 50%.

- The comparisons of fundamental period, storey drift, shear force, bending moment and axial forces are done in the linear elastic and nonlinear analysis in which the P-delta effect is not considered.

Literature Review

1. Structural analysis and modeling

Various literatures and previous studies were conducted to obtain the idea about the modeling process and the representation of infill in particular. Modeling of structures as a 3-Dimensional computer model generally creates no additional problems due to the irregularities in structure and soft storey effect (E L Wilson 2002). Strength, stability and rigidity are the important factors that are to be considered while modeling the distinct structural system to resist gravity and lateral loading. The building is considered to be a vertical cantilever as far as seismic loading is concerned and hence the influence of horizontal loading caused by the earthquake is more effective as the height of the structure increases, (Smith and Coull, 1991).

Moment resisting rigid frame system that mainly comprises of beam and columns connected by a moment resisting system is extensively used for the modeling of low rise building .In this modeling the joints created by each beam and column carries 6 degree of freedom .

For most of the buildings the stiffness of the frame members are generally considered low as compared to in-plane stiffness of the floor systems. Because of this the in-plane deformations of all the beams are neglected and the walls and columns are constrained to move as an isolated single unit in lateral directions. By using this property in the modeling we can reduce the dimension of the system of the equations of the building.

The analysis of structural system has significantly moved forward with the emergence of contemporary structural analysis tools such as fast computing and Finite Element Method (FEM).

2. LOADINGS ON STRUCTURES

Generally the structure is designed for the gravity as well as lateral loading in the seismic prone area. Gravity load that is the load acting because of the gravitational pull of the earth generally includes self-weight of the structure and the super imposed dead load .The calculation of dead weight is done by sizes of the designed member and with the help of the density of material used in the members. For the calculation of the live loads various loading estimates are specified in the code established on the combination of experience and results of typical field surveys.

Seismic loading is the load generated by the application of the earthquake agitation to a structure. The effect of earthquake generated translational inertia force is more effective as compared to the vertical and rotational shaking components on a building. The severe earthquakes are rarely occurred while the moderate ones occur more often and the minor earthquakes occur more frequently. The intensity or the magnitude of the earthquake is inversely proportional to their frequency of occurrence. Although the structure can be designed to resist severe earthquake without remarkable damage. General philosophies for the designing of earthquake resistant buildings are as following

1. Structure should be able to resist minor earthquakes without significant damage.

2. Structure should be able to withstand moderate earthquakes without any structural damage but receiving the chance of nonstructural damage.

3. Structure should be able to resist the average earthquake without collapse.

3. LATERAL DEFLECTION AND STOREY DRIFT

The lateral deflection must be limited to such extent such as to prevent the second order p-delta effects due to gravity loadings as far as ultimate limit state is considered. According to the limit state of serviceability the deflection must be limited to adequately low level such as to allow the proper functioning of nonstructural members such as lift, doors etc. The deflection should be minimum such as to stop the uncontrolled cracking and resulting loss of stiffness of the structure (Smith and Coull 1991). The Indian Standard IS 1893 limits the optimum inter-storey drift of 0.004 times the storey height and the optimum displacement of 0.002 times the height of the structure.

4. BASE FIXATION

In the absence of the structure the motion of the ground surface is called as free surface ground motion. Generally this free field ground motion is applied to the base of the structure supposing that the base is fixed. This assumption is valid for the structures on the hard rock sites and is not valid for the structures that are resting on the soft soil. Due to the soil-structure interaction the free field ground motion is somewhat modified and the base of the structure undergoes a motion that is different from the free field ground motion. The soil-structure interaction reduces the lateral forces on the structure and is responsible for the increase in horizontal displacements and the secondary forces related with the P-delta effect.IS-1893, 2002 suggests that this soil-structure interaction may be neglected for the ordinary buildings. IS: 1893: Part-1 (2002) suggests the soil –structure interaction as effects of the supporting foundation medium on the structure. The structure is considered to fix at base for the determination of the seismic loads (ASCE 7, 20005).Condition of the soil on which the building is resting governs the choice of support condition. The acceptance of the fixed support may be rationalized if the structure is resting on stiff soil or rock.

5. INFILLED STRUCTURE

Infilled frame structure comprises of the reinforced beam and column frame in which the vertical space is infilled with brick masonry or concrete block work. They are generally allocated as exterior walls, walls around lift or elevator and service shaft, partition walls etc. Infill walls are generally considered as non-structural elements. But in many studies it is treated as structural element which is equivalent to the bracing of the frame against lateral loadings. The frame is designed for the gravity loading but in the case of lack of any suitable design method they are assumed to give significant contribution to the stiffness of the structure to sustain the lateral loadings hence giving rise to the lateral strength. Due to the tremendously expertise in building infill structure and the ease of construction, the infill structures are considered to be the more rapid and in-expensive structural forms of buildings. It is more beneficial to organize the frame to withstand the total vertical and lateral loadings and to incorporate infill based on the assumption that they don't partake in primary structures, in the absence of accepted design method. This approach is not always reasonable due to the appearance of diagonal cracking in infill walls. The structure's behavior and the forces in members are somewhat modified because sometimes infill walls attract bracing load (Smith and Coull, 1991).

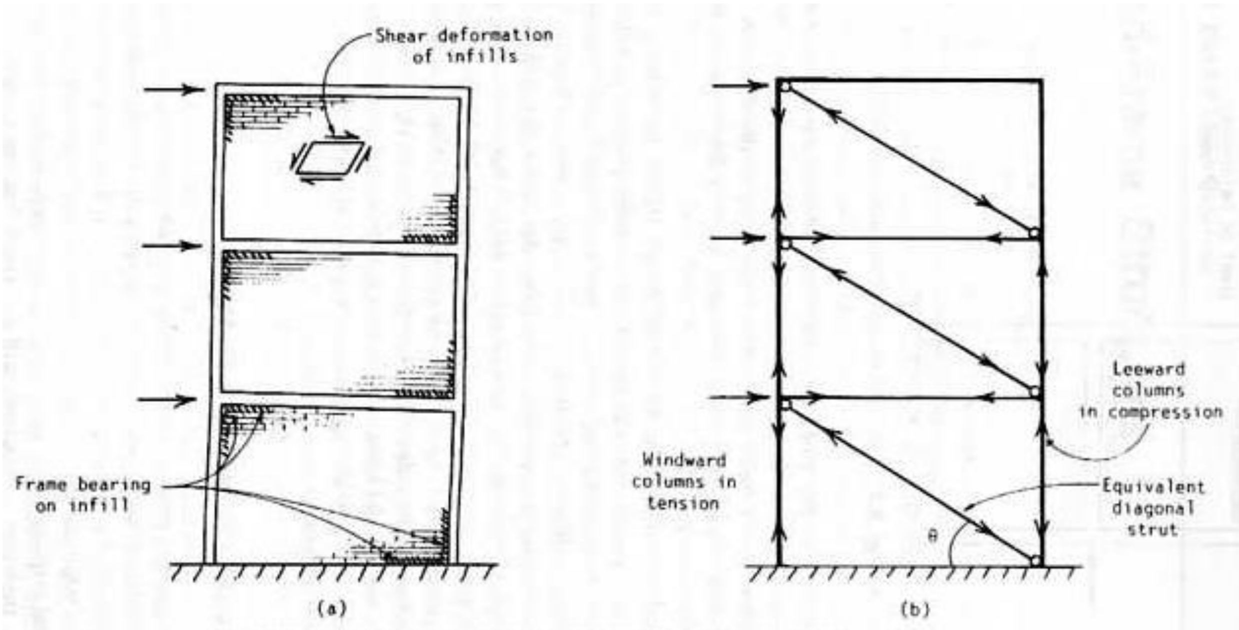


Figure 2 Equivalent diagonal strut model for infill (research paper F.Marjani and U.Ersoy)

The treatment of infill masonry as a bracing to infill frame remarkably stiffens the frame. When the structure is subjected to horizontal loading to seismic excitation the movement of the upper portion of the column causes the column to bend against the wall resulting to the shortening of the leading diagonal of the frame. This is equivalent to the diagonally braced frame as shown in the figure. There are three probable modes of failure of the infill wall as a result of its communication with the frame. The first one is the shear failure in which the crack moves down through the junctions of the masonry and it is accelerated by the lateral shear stress in the bottom joints. The second one is the diagonal cracking which propagates in the wall along the lines that is parallel to the principal diagonal due to the tensile stresses vertical to the principal diagonal. Due to the excessive compressive stresses in the corner, the corner of the infill at the ends may be wrinkled against the frame. This is categorized under third mode of failure (Smith and Cull, 1991).

6. RESPONSE OF BRICK INFILLED MASONRY WALLS

As discussed earlier to understand the effect of infill masonry on the lateral strength and stiffness of structures various experiments have been conducted since early 50's. A systematic model of force deformation response of infill is required to correctly analyze the infilled structures. Numbers of finite element models has been evolved to foresee the behavior of infilled frames (Asteris 2003; Shing et al.1992; Dymiotis et al 2001 ;), such type of modeling is too time taking for the investigation of the large structures. Hence the most popular approach is a macro-modeling substituting the entire infill as single equivalent strut.

The study of the complicated behavior of masonry infill by polyakov (1956) suggested that the infill and frame disparate excluding at two compression corners. He established the idea of equivalent diagonal strut and proposed that transformation of stresses from the frame to infill occurs only in the compression zone of the infill.

Another study conducted by Holmes (1961) suggested that the infill can be replaced by equivalent diagonal strut that is pin jointed at corners and is of same thickness and material and its width is equal to one third of the diagonal.

The study on infill done by Bryan and Stafford Smith (1962) is considered to be the major contribution towards the study of infill walls. He suggested that the separation of the frame from the infill is spanned over three-fourth of the length of each side. He proposed modeling of infill as a diagonal strut whose effective width is governed by the following equation.

$$\lambda h = \sqrt{\frac{Ect\sin 2\theta}{4E'I'h'}} \quad \text{and} \quad \frac{\alpha}{h} = \frac{\pi}{2\lambda h}$$

where h is the height of the column, E_c and E' are the young's modulus of the elasticity of the frame and infill panel respectively is the thickness of the infill panel, θ is the angle of inclination of diagonal strut with the horizontal, I' is the moment of inertia of the column and h' is height of the infill.

Another study carried out by Pauley and Priestley (1992) proposed that effective width should be equal to the one fourth of its leading diagonal. Mainstone (1971) suggested the following equation for the width of the infill

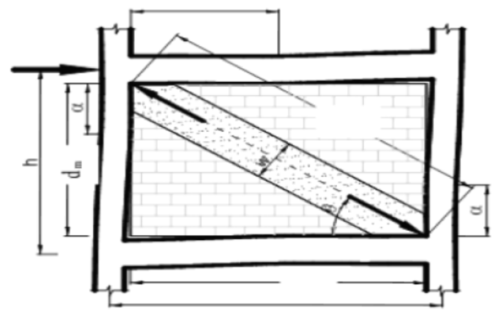


Figure 3 Infill replaced with equivalent diagonal (www.ijser.org)

$$\frac{w}{d} = 0.175(\lambda h)^{-0.75}$$

Liaw and Lee (1977) conducted some experiments and analytically examined the effect of concrete infill with and without openings. They proposed that for the analysis of frames without connectors the equivalent diagonal strut method is more suitable and for the equivalent frame method is more suitable for the frame with connectors.

RESEARCH METHODOLOGY

1. LITERATURE REVIEW

To acquaint with the theoretical part various publication and research articles were investigated on the effect of masonry infill on moment resisting reinforced concrete frame structures. In addition to this various books and design codes were studied. The motivation of literature review was to obtain the vague knowledge on the methods of studies adopted so that it can be used as guide lines for the present work. The investigation of past studies help in modeling methods and parameters to be used for materials like concrete and brick masonry.

2. DATA COLLECTION

Various Indian standard codes were collected from the department of civil engineering NIT Rourkela. The earthquake data's were obtained from the site Peer.berkeley.edu. The earthquakes considered in this work are Imperial Valley, San Francisco and IS code.

3. METHODOLOGY ADOPTED

As discussed earlier, in current practice the masonry infill is treated as nonstructural element in structural analysis that is the strength and stiffness characteristics are not considered in the analysis. The infill is designed by assuming that infill only contributes to the mass of the structure and the other characteristics are not considered. Thus the structure can be modeled as bare frame and infill frame model. In both types of model the base is considered to be fixed. In India the analysis of structure for seismic loading is done as per IS

1893(Part I: General Provisions and Buildings). Modeling of the building is done as 3-dimensional finite element model in which the beams and columns form frame elements which has ability to deform axially and in shear, bending and torsion.

This work involves a theoretical 6 storey apartment cum building whose plan is given in the following figure. This building is not the representative of any physical existed building. The building is unsymmetrical in plan that is the building is spanning more in x direction and less in z direction. The plan dimension of the building is 25×15 meter square and the height of the building is 16.75 meter. Spacing of the grid is 5 m in both x and z direction. The height of each floor is 3.35m. The vertical space created by beams and columns is treated as masonry infill. Only the walls enclosed by beams and columns are treated as masonry infill and only the weight contribution is considered for the other location of walls. The sizes of members are shown in the following table 1

Table 1

Structural members	Sizes of the members
Infill	200 mm
Beams	300mm x 600 mm
Columns	500mm x 500 mm

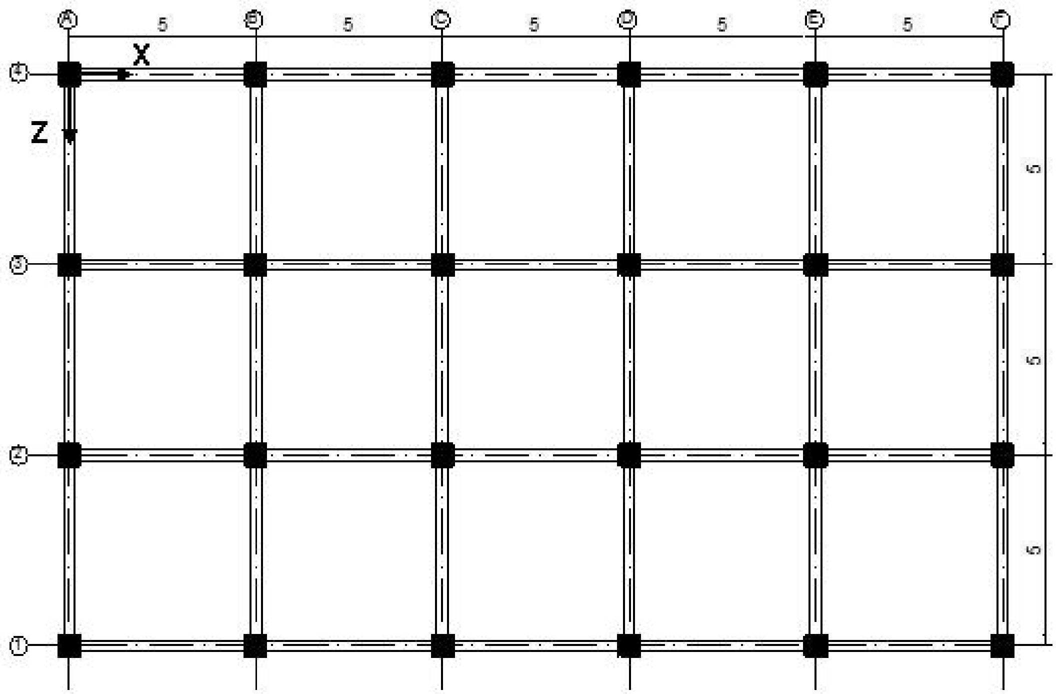


Figure 4 Plan of the building

The dimensioning of the beams and columns are made as per IS 1893 -2002 according to the strength and ductility requirements. For the structures in which the infill has the opening the same member sizes are used. Openings are concentrated on the center and there is no integral bonding of frame with the infill panels. To study the seismic behavior of the infill structures different models were created as bare frame model, infill model and the infill with 20% and 50% openings in them. The time periods given in the code and calculated time periods are studied for these structural models. To model the infill two different approaches are used as following

1. BARE FRAME METHOD

It is the most frequent model of structural analysis for the building with infill panels all around the world. In this method the masonry infill is considered to contribute only to the mass of the structure and it is regarded as nonstructural element that why it is called bare frame method. In this method beam and columns are treated and designed as a frame member. The contradiction may occur in the analysis and seismic response of the structure because the strength and stiffness characteristic of the infill is not considered. Although this model is still used in the most parts of the world even in seismic prone areas.

2. EQUIVALENT STRUT METHOD

The most accepted method for the analysis of infilled frame structures is equivalent strut method in which the entire infill is replaced by a single equivalent strut. In this method, beams and columns are designed as frame members which are having 6 degrees of freedom at every node and the brick infill is replaced by a pin jointed diagonal strut. The thickness of the pin jointed diagonal strut is considered to be the same as infill and its length is equal to the length of the diagonal between the two compression corners. Relative stiffness of the frame and infill, contact length and the aspect ratio are general parameters that govern the effective width of the equivalent diagonal. The frame infill interaction is neglected in this method.

Load cases used:

Dead load: Dead loads are calculated with the help of the unit weight of the materials assigned to the framing members. Indian code used is IS 875 (part I)

-1987 code of practice for the design loads other than earthquake loads for building and structures.

Imposed load : The imposed load is based on the Indian standard code IS:875 (Part 2) – 1987 code of practice for design loads other than earthquake loads for building and structures, Part 2 Imposed load (Second revision).

Earthquake load: The earthquake load is based on Indian Standard IS 1893 (Part 1): 2002, Criteria for Earthquake Resistant design of Structure, Part 1: General Provisions and Buildings (fifth revision).

To study the seismic behavior of the masonry infill structures three different structural analysis is done

1 Response spectrum analysis

2 Equivalent static analysis

3 Time history analysis

RESPONSE SPECTRUM ANALYSIS

Irregular buildings with the height less than 12 m in earthquake zone V that is the most severe zone and the buildings having height less than 40 m and are regular, is restricted to the equivalent static lateral force analysis. Multiplication of total load and the reduced live load with a coefficient obtained from the response spectrum curve give rise to the seismic weight of the structure. The plot is shown in the following figure.

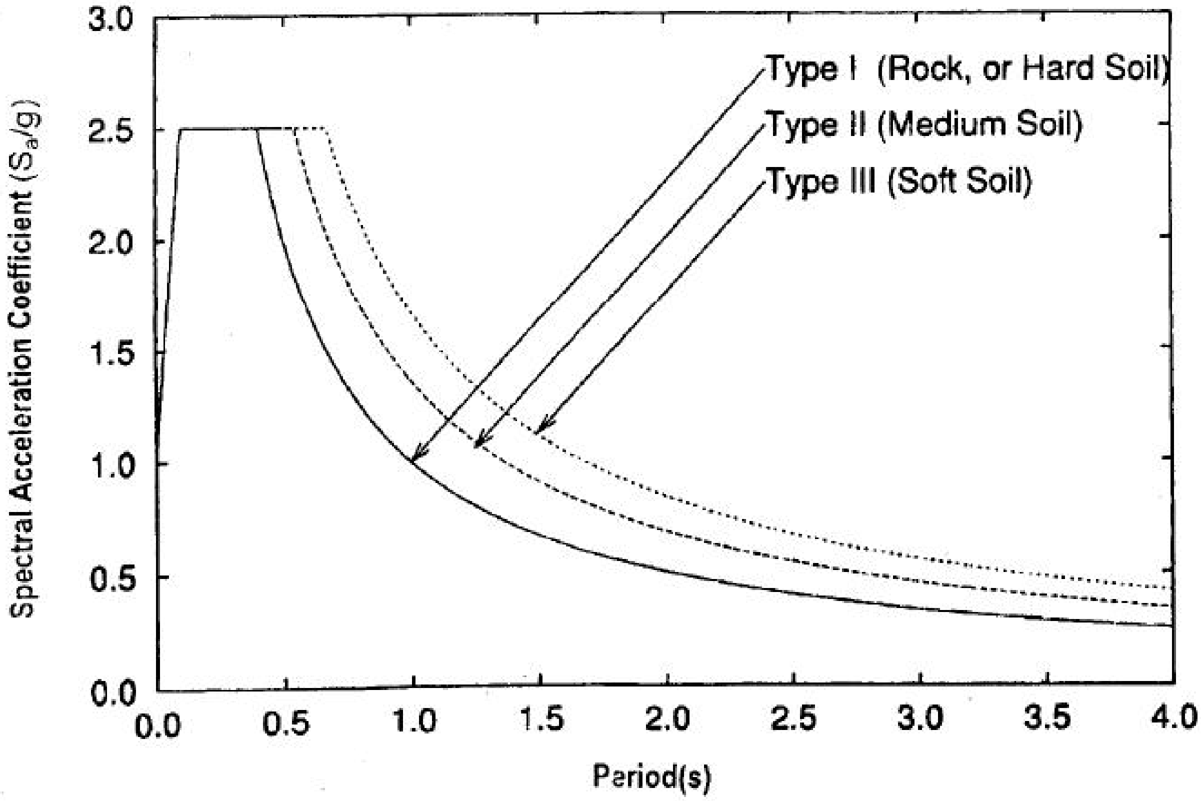


Figure 5 Response spectrum curve for 5% damping

The total horizontal force at the base of the structure that is also called design base shear is calculated in accordance with the clause 7.5.3 of the code which states that

$$VB = AhW$$

Where,

$$Ah = \frac{Z\ I\ Sa}{2\ R\ g}$$

Provided that for any structure with T < 0.1 sec, Ah is not less than Z/2 whatever be the value of I/R

Z = zone factor = 0.36; I = importance factor =1.5; R = response reduction factor = 5, Sa/g = Average response acceleration coefficient from the response spectrum figure which depends on the fundamental time period of the building and the total load and a specific amount of imposed load that is W = seismic weight of the structure.

The fundamental time period of a moment resisting frame is given by

Ta = $0.075h^{0.75}$ for RC frame building;

Ta =$0.085h^{0.75}$ for steel frame building;

Ta = $0.09h/d^{1/2}$ for moment resisting frame with brick infill panels

In which h is height of the building in meter, d is the base dimension of the building at plinth level along the direction of considered lateral force.

The design base shear is calculated from the following formula

$$Q_i = \frac{W_i\, h_i 2}{\in W_j\;\; h_j 2}$$

Where Q_i = design lateral force at the floor I, Wi = seismic weight of the floor hi = height of the floor measured from the base and n= number of the storey in the building.

STATIC ANALYSIS

In this analysis the total base shear is distributed throughout the height of the structure. Based on the seismic coefficient that is depending upon the complete weight of the structure and the seismic risk exposure of the certain location.

However it is a static analysis, some of the dynamic property of the structure is embodied in terms of fundamental period and response reduction factor.

TIME HISTORY ANALYSIS

It is a nonlinear evaluation of dynamic structural response under the loading which may differ according to the specified time function. The basic governing equation for the dynamic response of a multi degree of freedom system is given as

$[M]\{\ddot{x}(t)\} + [C]\{\dot{x}(t)\} + [K]\{x(t)\} = F\{x(t)\}$

Where $[M]$ = mass matrix

$[C]$ = damping matrix

$[K]$ = stiffness matrix.

And $\ddot{x}$ = acceleration

$\dot{x}$ = velocity

x = displacement

$F(t)$ = inertial forces due to seismic activity

The given equation can be solved by numerical integration method such as runge-kutta method, Newmark integration method and wilson-ϴ method. The STAAD PRO software calculates the structural responses at each time step and thus solves the governing dynamic equation. In the present work, two different time steps are used for the building one is 0.005 and other is 0.01. This time step provides proper convergence of results.

In this work time history analysis is done only for three earthquakes namely:

1) Imperial Valley
2) San Francisco
3) IS code ground motion data

This ground time history acceleration data are collected from the site of Pacific Earthquake Engineering Research Center.

The ground motion of these earthquakes are shown in the following figures

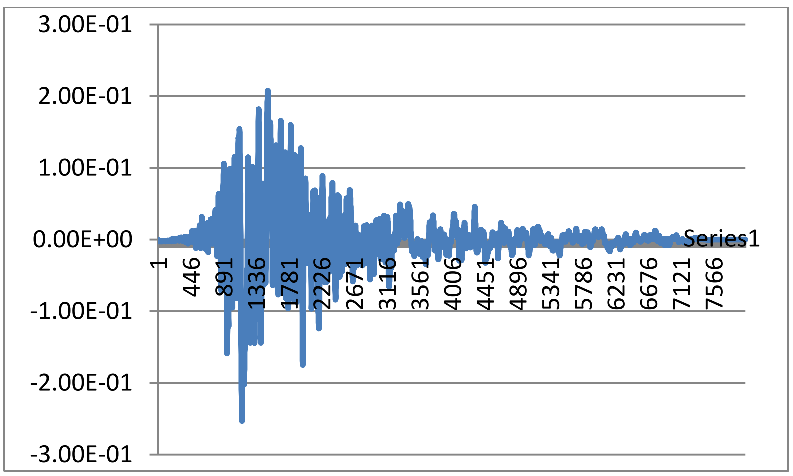


Figure 5 Imperial Valley earthquakes

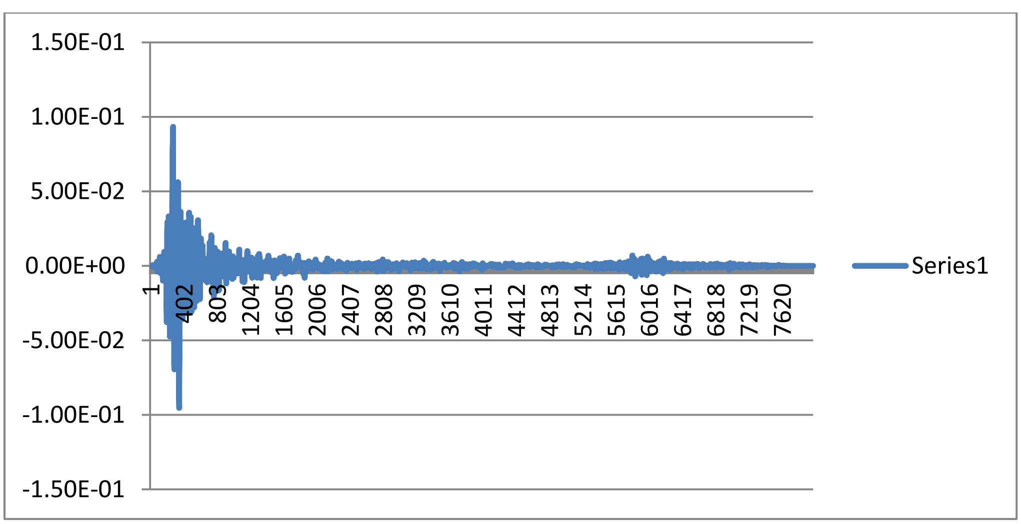


Figure 6 San Francisco earthquakes

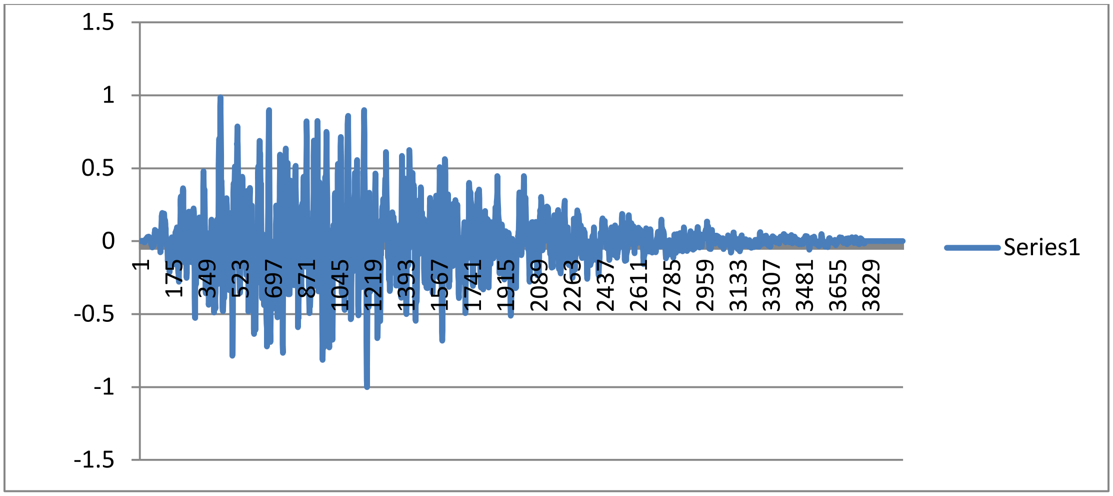


Figure 7 IS code ground motion data

MATERIALS PROPERTY USED

The material used for the beam and column is concrete and the vertical space created by this is filled with brick masonry infill.

CONCRETE

Unit weight of concrete = 23.5616 KN/m2

Characteristic compressive strength =M30 = 30 N/mm^2

Shear strength = 3.5N/mm^2

Young's modulus of elasticity=27.718KN/mm^2

Poisson's ratio = 0.17

Shear modulus = 11.703N/mm^2

Flexural strength = 3.83N/mm2

BRICK INFILL

Mortar ratio = 1:3

Tensile strength of brick = 0.75N/mm2

Young's modulus of elasticity = 4125N/mm2 , Poisson's ratio = 0.1

RESULT AND DISCUSSION

The interpretation of the result is entirely based on the global responses of the structure and it doesn't take the micro level responses into account. Storey drift, roof displacement, axial forces, bending moment, base shear, fundamental time period are the major behaviors that are studied and compared in this project work. The present study was done for the bare frame, infill frame and the infill frame with 20 and 50 % opening. Based on the results obtained comparison was made for the storey drift, axial forces shear forces, base shear, fundamental time period and bending moment. First the comparison for the storey drift, axial forces bending moment, shear forces is done with equivalent static and response spectrum analysis for bare frame and infill models. Next the structural responses for the bare frame, infill frame and the infill frame with openings are compared by using time history analysis. However the Pauley and Priestley model for modeling the infill frame seems most suitable as seen in the verification chapter, Holmes and FEMA model were considered for the modeling of infill panel.

1. EFFECT OF FULL INFILL WALL ON RC FRAME STRUCUTRE

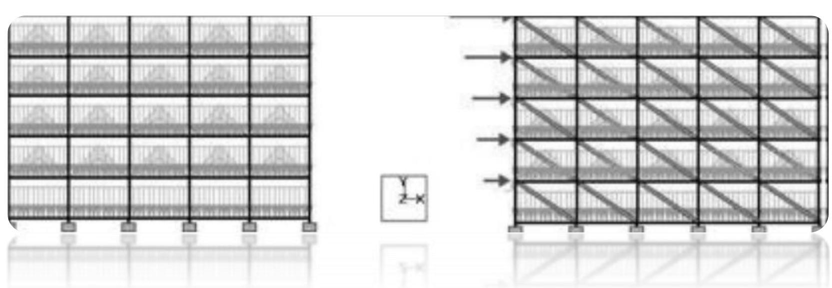


Figure 8 bare frame and infill frame with full wall

1.1Effect on storey drift

The effect of infill was studied on the storey drift of bare and infill frame and it was observed that in the infill panel the storey drift is drastically reduced. Hence significant effect of infill was observed. The effect of infill on the storey drift (in X and Z direction) of the moment resisting RC frame with equivalent static and response spectrum is given in the following table 2 and table 3 respectively .

STOREY DRIFT IN X DIRECTION (CM)

Table 2

Storey	Equivalent static		Response spectrum	
	With infill	Without infill	Without infill	With infill
1	0.0	0	0	0
2	10.319	13.16	1.33	0.024
3	16.296	24.578	2.218	0.038
4	15.590	25.612	1.893	0.03
5	12.257	21.657	1.320	0.018
6	8.039	15.112	0.703	0.01

STOREY DRIFT IN Z DIRECTION (CM)

Table 3

STOREY	EQUIVALENT STATIC		RESPONSE SPECTRUM	
	WITH INFILL	WITHOUT INFILL	WITH INFILL	WITHOUT INFILL
1	0	0	0	0
2	7.439	9.686	1.521	1.743
3	11.488	17.778	2.218	2.284
4	10.902	18.342	1.893	2.095
5	8..715	15.384	1.320	1.609
6	5.4840	10.544	0.703	1.013

The variation of storey drift with storey level is shown in the following figure 9:

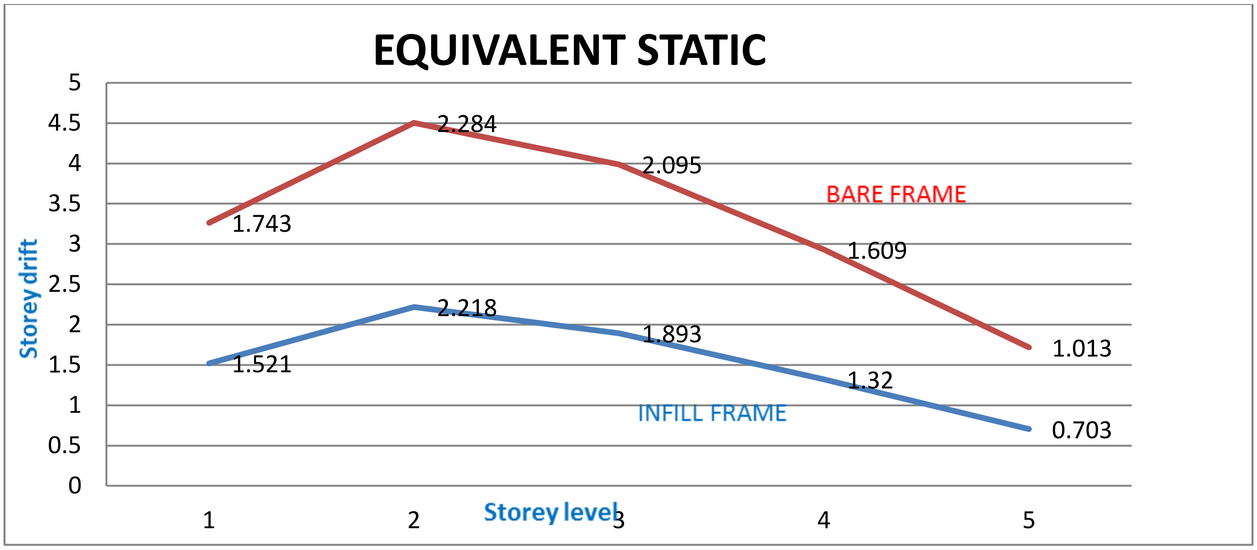


FIGURE 9

Due to the introduction of the infill storey drift is drastically reduced as shown in the figure 10.

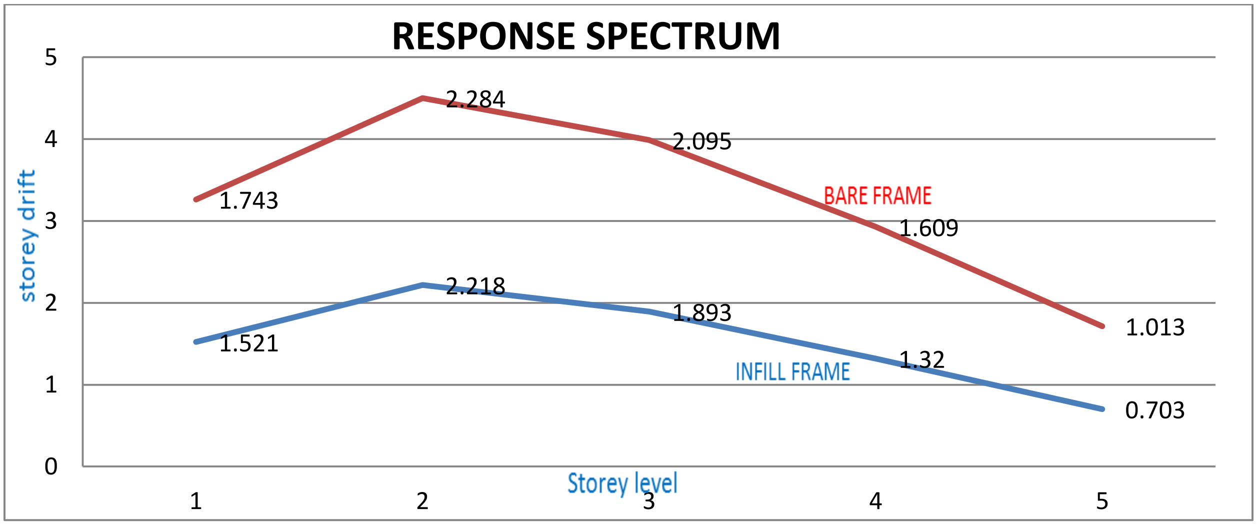


Figure 10

1.2 EFFECT ON MEMBER FORCES After that the effect of infill on the member forces were studied .It was found that the infill model speculated more axial forces in column and the reduction of shear force and bending moment in both columns and beams was observed.

The comparison of the axial forces for the floor wise corner column are shown in the table 4

AXIAL FORCES IN FLOOR WISE CORNER COLUMNS (KN)

Table 4

FLOOR	EQUIVALENT STATIC		RESPONSE SPECTRUM	
	WITHOUT INFILL	WITH INFILL	WITH INFILL	WITHOUT INFILL
1	79.45	127.69	323.19	13.46
2	64.58	187.51	252.36	13.27
3	60.46	176.31	180.87	13.92
4	50.10	141.71	109.06	14.34
5	23.63	93.18	36.98	14.29

It can be seen that for the bottom columns the axial force is greater in infill frame model as compared to the other columns.

Similarly it was observed that the impact of infill reduces the shear forces on beam and columns. The effect of infill on shear force in some selected beams that is residing on the edges of the frame is shown in the table 5:

SHEAR FORCES ON EDGE BEAMS (KN)

Table 5

BEAM	EQUIVALENT STATIC		RESPONSE SPECTRA	
	INFILL	WITHOUT INFILL	INFILL	WITHOUT INFILL
55	26.30	26.62	18.16	18.37
165	46.77	64.85	18.26	18.42
250	47.05	67.05	17.95	18.32
306	24.77	26.00	18.18	18.46

PEAK STOREY SHEAR (KN)

Table 6

FLOOR	EQUIVALENT STATIC		RESPONSE SPECTRUM	
	WITHOUT INFILL	WITH INFILL	WITHOUT INFILL	WITH INFILL
1	45.178	72.247	323.75	740.65
2	180.714	288.989	323.75	740.65
3	406.605	650.226	302.48	683.55
4	722.854	1159.577	255.13	564.39
5	1070.476	1445.291	190.91	400.90

The effect of infill on peak storey shear is shown in the table 6. And the bar chart comparison for axial forces is shown in the figure 11.

SHEAR FORCES IN EDGE BEAMS (BAR CHART)

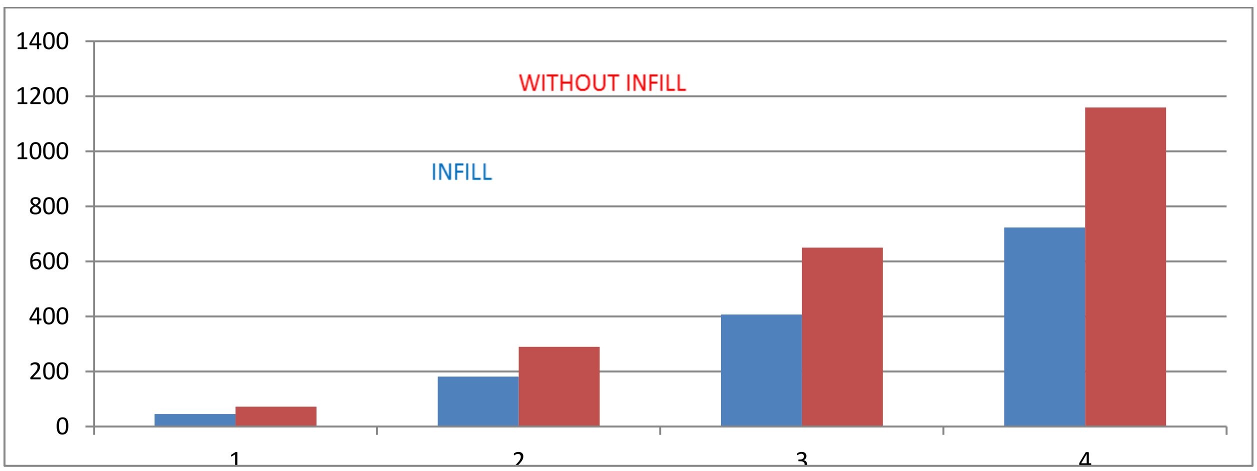


Figure 11 shear force for infill and without infill

The variation of peak storey shear for the bare frame an infill model for equivalent static model is presented in the following figure 12:

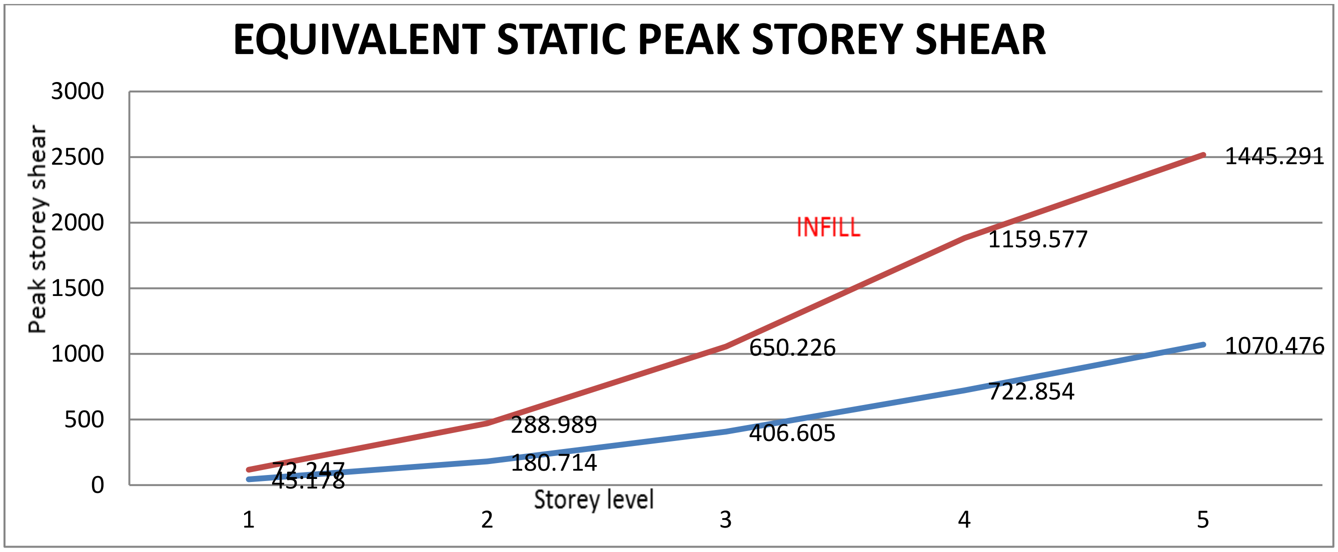


Figure 12 Peak storey shear for bare and infill

2. EFFECT OF INFILL WALLS ON RC FRAME WITH DIFFERENT OPENING SIZES

In this case the effects of full and partial infill walls were comparatively studied. Apart from the full infill, 20% and 50% opening were considered.

2.1 FUNDAMENTAL TIME PERIOD AND BASE SHEAR

In this study it is found that the bare frame model shows longer time period as predicted by the code whereas the infill frame model predicts fundamental time period closer to the value as predicted by the code.

It was found that as the infill frame with smaller opening sizes predicts time period more close to the value predicted by the code. This is due to the fact of additional stiffness provided by the infill to the whole structure.

Similarly it was found that the base shear calculated on the basis of infill frame model predicted much greater value than the code while the bare frame model gave somewhat closer value of base shear to the value calculated from the code.

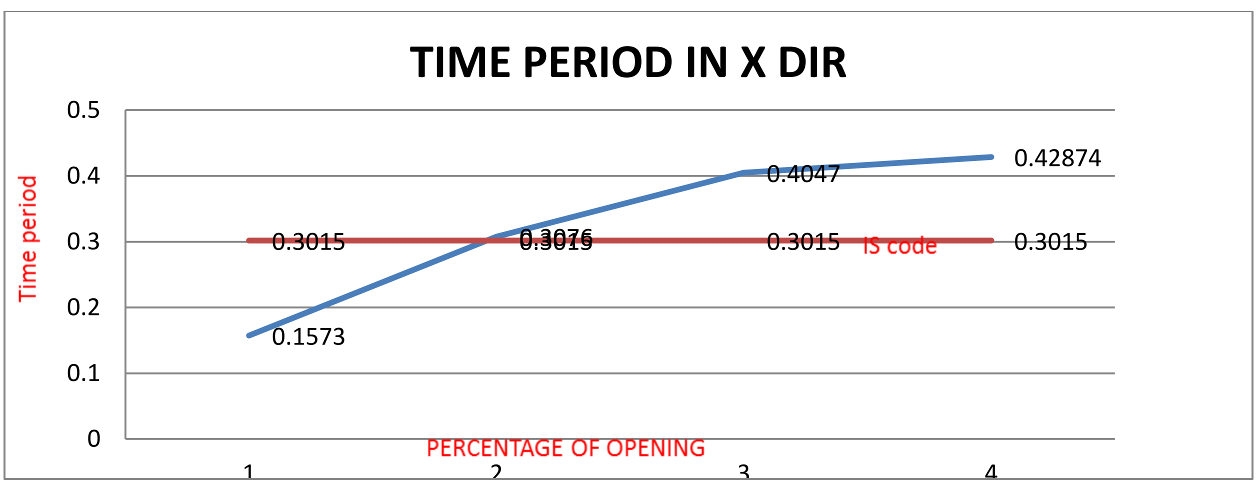
The base shear differs with the opening sizes as the effect of infill is considered. As the size of opening increases the base shear tends closer to the value as predicted by the code.

For various opening sizes the time period in x direction is shown in the following table 7:

Table 7

X DIR	IS CODE	BARE	20%OPEN	50%OPEN
TIME PERIOD(s)	0.3015	0.42874	0.3076	0.40407
BASE SHEAR(KN)	1198.56	13280	16801	16540

The variation of fundamental time period with the percentage of opening is shown in the following figure 13:



2.2 EFFECT ON STOREY DRIFT

The effect of partial and the full infill wall on the storey drift were studied using time history analysis. Introduction of infill in the building structure reduces the seismic demands of the building both in terms of storey drift and the horizontal displacement.

The storey drift for the bare frame, full infill ,infill with 20% and 50% opening for all the three earthquake is shown in the following table 8

STOREY DRIFT IN CM

Table 8

Storey	Imperial			Is code			San Francisco		
	Bare	Infill	Opening (50%)	Bare	Infill	Opening (50%)	Bare	Infill	Opening (50%)
1	0	0	0	0	0	0	0	0	0
2	0.6759	0.1070	0.5893	3.3844	0.4549	2.7516	0.0445	0.0281	0.0354
3	1.5900	0.2223	1.3556	7.9797	0.9496	6.4405	0.2016	0.0576	0.1916
4	2.3545	0.3220	1.9600	11.8075	1.3792	9.6296	0.2983	0.0246	0.2824
5	2.8766	0.3969	2.8362	14.3831	1.7034	11.969	0.3876	0.0016	0.0794
6	3.1433	0.4427	3.0531	15.6753	1.9005	13.2404	0.4617	0.0004	0.4590

Variation of storey drift with storey level for different openings figure 14:

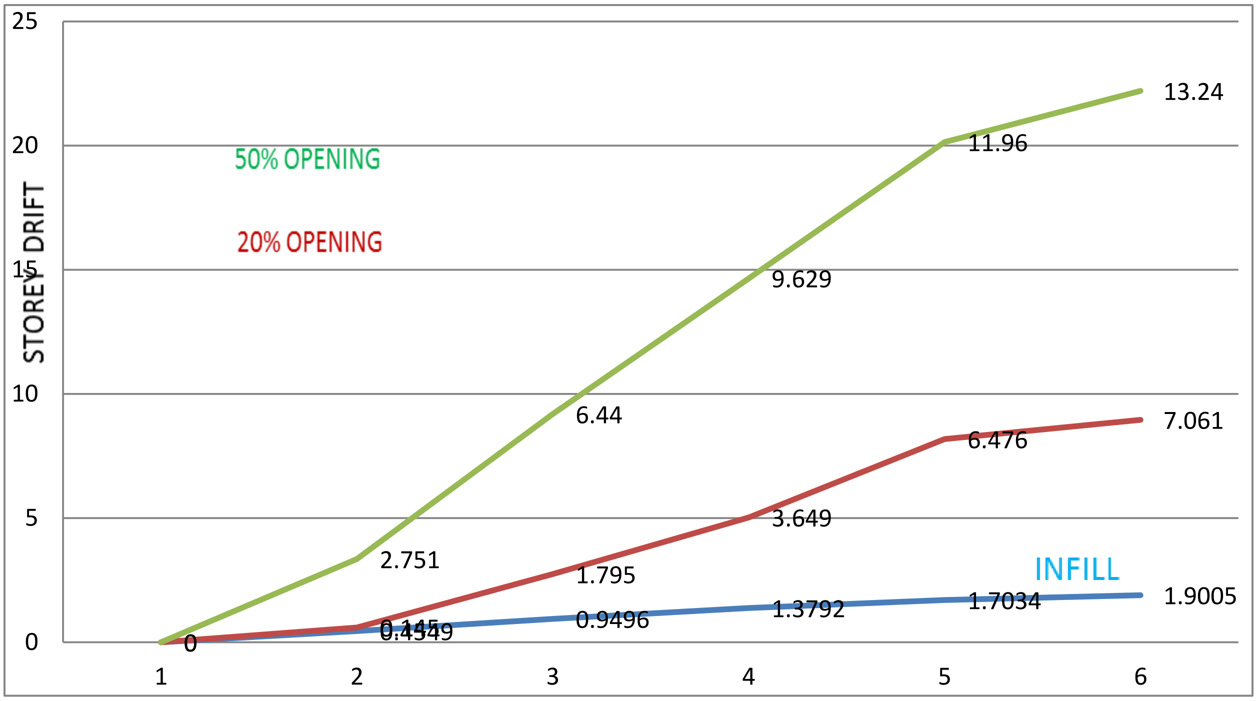


Figure 14 storey drifts variation for 3 different cases

2.3 MEMBER FORCES

Next the study of the member forces with partial and full infill was done.

Axial Forces in corner column

The corner columns were chosen for the bare, infill and it was found that the introduction of infill causes the increase in axial forces in columns.

The comparison of axial forces for the bare frame and infill frame for three different earthquakes are shown in the following table 10:

AXIAL FORCES IN CORNER COLUMNS (KN)

Table 10

Column	**Imperial**		IS **Code**		**San Francisco**	
	Bare	Infill	Bare	Infill	Bare	Infill
1	352.74	375.37	1422.72	1636.25	102.03	191.00
87	279.12	395.42	1119.57	1516.90	5.92	88.32
173	205.22	268.46	658.54	1022.98	30.44	45.62
259	65.71	102.15	281.80	466.53	11.60	58.88
260	32.00	49.42	94.89	172.89	8.22	13.40

The bar-chart of the axial forces is shown in the following figure for Imperial Valley earthquake:

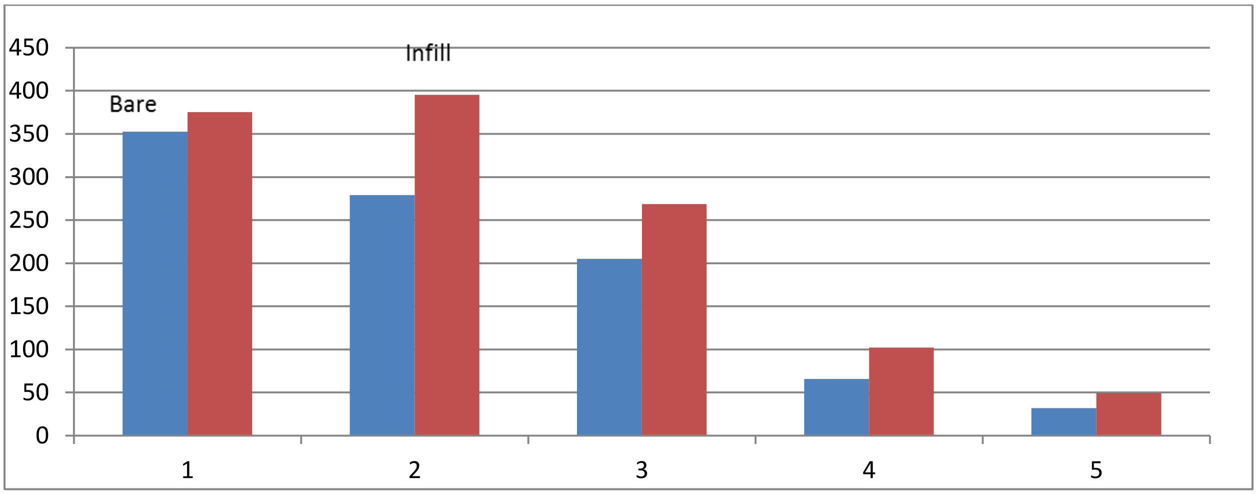


Figure 14 Variation of axial force for infill and bare frame

Bending moment in corner columns

The corner and middle columns was chosen for the bare, infill and the infill frame with 20% and 50% opening, and it was found that the introduction of infill causes the reduction in bending moment.

The bending moment of corner columns for all the three earthquakes are shown in the table 11.

The bar-chart of bending moment for infill, infill with 20% and 50% opening are shown in the figure

It can be seen that the reduction in bending moment for the smaller opening is more because the smaller opening has the more effective infill that is the effect of infill is more in smaller opening as obvious.

BENDING MOMENT IN Z DIRECTION (KN-M)

Table 11

COLUMN	IMPERIAL			IS CODE			SAN FRANS.		
	INFILL	20%	50%	INFILL	20%	50%	INFILL	20%	50%
1	23.83	55.01	91.42	104.52	196.71	328.4	14.37	6.32	12.23
2	14.93	38.44	107.3	54.71	192.42	414.2	10.31	3.90	13.20
3	40.32	93.82	147.7	176.71	351.95	604.4	22.16	21.39	22.04
4	2.99	36.91	72.73	31.40	123.66	343.0	0.28	16.84	14.51

BAR CHART OF BENDING MOMENT IN Z DIRECTION FOR IMPERIAL VALLEY

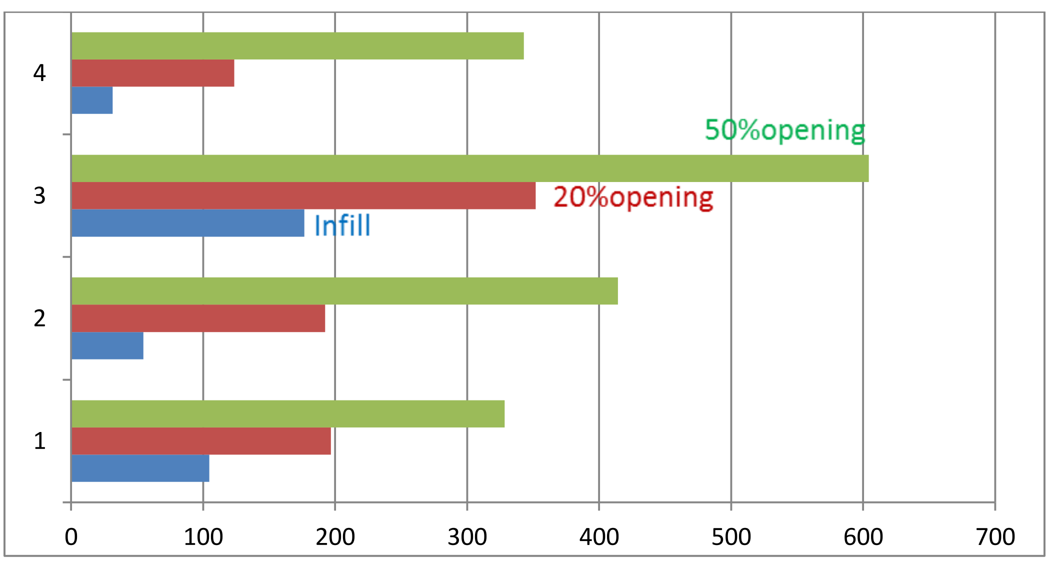


Figure 15

BAR CHART FOR THE BENDING MOMENT FOR IS CODE

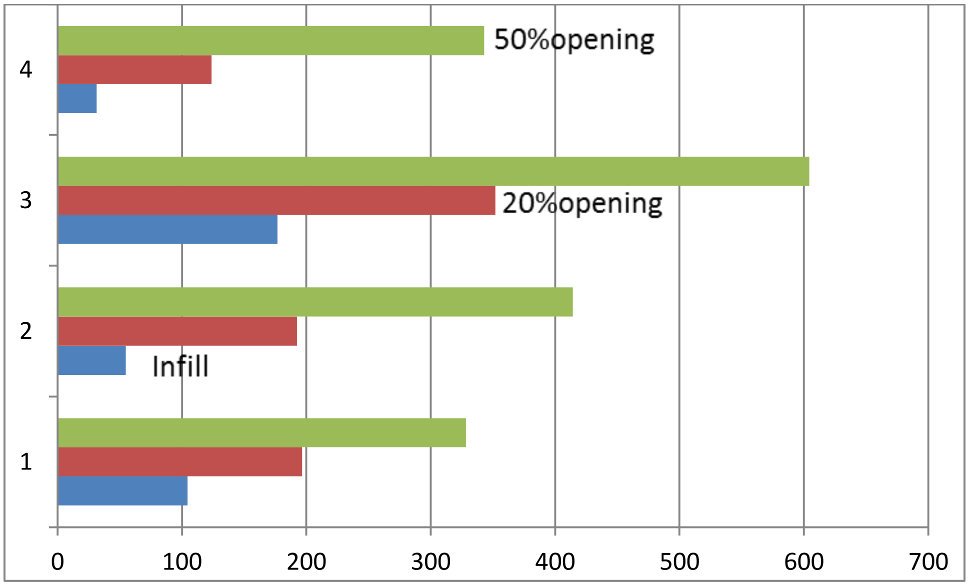


Figure 16

2.4 MAXIMUM ROOF DISPLACEMENT

The maximum roof displacement curve was generated from the post analysis modeling of STAADPRO for bare frame, infill frame and the infill frame with opening of 20 and 50 %.

The maximum roof displacement was found to be more for bare frame model as compared to the infill frame model. It is due to the fact that consideration of infill enhances the strength and stiffness characteristic of the moment resisting reinforced concrete structures.

It was also found that opening sizes affected the max roof displacement as the size increases the max roof displacement increase.

The time displacement plot(for the IS code earthquake) of the roof of bare frame ,infill frame and the infill frame with 20% and 50% opening are presented here.

Time-displacement plot of infill frame without opening figure 17

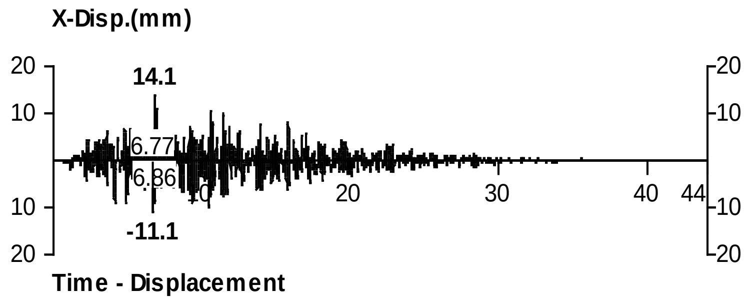


Figure 17 time displacement plot for infill

Time –displacement plot of infill with 20% opening

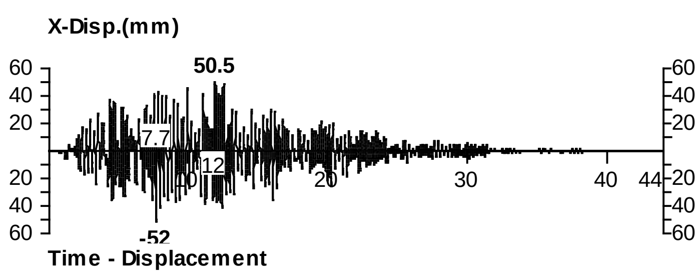


Figure 18

Time displacement plot of infill with 50 % opening

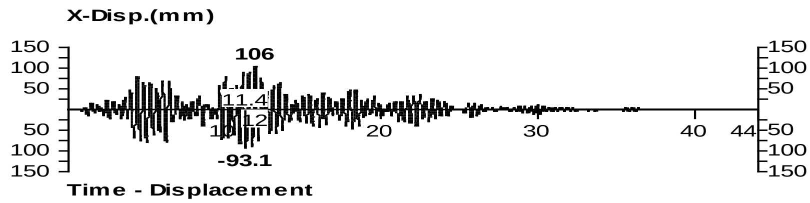


Figure 19

Time –displacement plot of bare frame

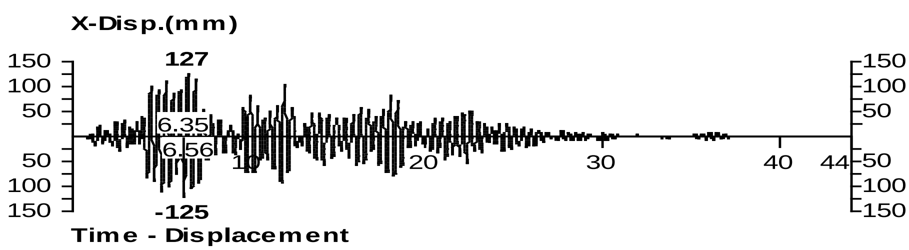


Figure 20

CONCLUSION

Almost every multi-storey building is made up of moment resisting RC frames in most of the developing countries. Brick infill masonry or concrete masonry are mostly used to infill the vertical space created by the beams and columns in the frame. These infill panels are generally not the intrinsic part of the moment resisting frame and usually they have openings in them for the utilitarian demand of doors, windows etc.

There are advantageous and disadvantageous effect of infill masonry according to the previous studies and experience obtained during earthquake. There is increase in overall lateral strength. Damping of the structure is also affected by the infill walls; increase in damping of the structure due to the effect of infill causes the increase in energy dissipation capacity of the structure. In addition to that the total horizontal displacement and the storey drift of the structure are greatly reduced by the introduction of infill in moment resisting reinforced concrete frame. However there are disadvantageous effect of infill such as soft storey and short column effect.

Due to the lack of well accepted seismic design basis past engineers incline to treat the masonry infill as a non-structural element that is the strength and stiffness characteristics are not considered in the design. Many researchers developed a number a macro-model to include the strength and stiffness parameters but by far, the equivalent diagonal strut model is more popular. In this model the entire infill is replaced by a pin jointed equivalent diagonal strut with each node having 6 degree of freedom.

This project work is a small endeavor to perceive the effect of masonry infill to the moment resisting RC frame under earthquake loading. The main conclusion is encapsulated below:

- Infill model predicted the closer value of fundamental time period with the IS code value than the bare frame model. As the size of opening was decreased the model predicted stiffer structure than predicted by the code, that is the time period is closer to the code prescribed value when the size of opening is decreased.

- The seismic requirement of the structure in terms of storey drift and the maximum average roof displacement of the structure are markedly enhanced by the introduction of infill. As the opening size is increased the maximum roof displacement and the storey drift is increased. As compared to the bare frame the maximum roof displacement is reduced by 88.89 %, 60.24% and 16.54% for full infill, infill with 20% opening and infill with opening 50% respectively.

- Primary frame action of a moment resisting frame is converted to the primary truss action due to the introduction of the infill leading to the increased axial forces in column in infill frame model.

- The response of the structure in terms of bending moments and shear forces is greatly enhanced by the introduction of the infill. Both bending moment and shear force in beams and columns are reduced appreciably due to masonry infill.

RECOMMENDATION

1. Bare frame model predicts notably longer time period than the code prescribed value. Although when the effect of infill is taken into consideration the model predicts time period more closely to the code prescribed value. The infill increases the stiffness of the structure. This increased stiffness leads to the shorter time period. Further study may escort to the more empirical way to calculate the fundamental time period using logical approach like modal analysis.

- To evaluate the natural time period the IS code gives an empirical relation that depends on the width and height of the building only, further study may be carried out to find the influence of number of span , span length and the stiffness of the members etc.

- This project work was done with the no infill, full infill and the partial infill with only 20% and 50% openings. This work may be extended to the different opening sizes and with different aspect ratio.

- This work was involved with the symmetrical arrangement of the infill further study can be worked out for unsymmetrical arrangement of infill.

- This work can be continued to a building structure with higher number of stories to establish the effects of infill on high rise or tall buildings.

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APPENDIX

Calculation of effective width of equivalent diagonal strut

In a moment resisting frame exterior walls, walls around stairs and partitions etc. are provided in terms of masonry infill and they are treated as nonstructural element in usual practice. But by various studies it has been shown that masonry infill serve as a structural element and plays an important role in enhancing the lateral strength and stiffness characteristic of the structure. When the horizontal load acts on the structure due to earthquake the movement of the upper part of column tends to compress the leading diagonal thereby leading to the shortening of the leading diagonal. So this system is analogous to the frame subjected to the bracing that is braced frame.

So the RC frames are modeled as infill frame in which the infill masonry is replaced by the equivalent diagonal start of same material as that of the infill. Various researchers recommend different values to calculate the width of the strut.

In this work the width of strut is calculated as suggested by the FEMA 273. The following equation is used to calculate the width w:

$$\frac{w}{d} = 0.175(\lambda h)^{-0.75}$$

$$\Lambda h = h \times \sqrt{\frac{\mathbf{Em}t \sin 2\theta}{4E'I'h}}$$

Where h is the height of the infill and E_m and E' is the young's modulus of elasticity of the frame and infill material and w is the effective width of the diagonal strut.

Appendix table for width of diagonal sturt

Opening%	Opening size(mm)	Diagonal length(mm)	Width (mm)
20	1570*1570	3169.8	354
50	2490*2490	2879.2	335